

We claim:

1 1. A method for improving a thermal barrier coating comprising:
2 providing a substrate;
3 providing a nanocrystalline, nano-composite bond coat on the substrate; and
4 providing a ceramic top coat on the nanostructured nano-composite bond coat.

1 2. The method of claim 1 where providing the bond coat on the substrate and
2 providing a nanocrystalline nano-composite coating comprises providing a bond coat
3 composed of nanocrystalline MCrAlY, where M stands for either Co, Ni and/or Fe, using
4 a thermal spray process onto a metallic substrate, and where providing the ceramic top
5 coat on the nanostructured, nano-composite bond coat comprises providing a yttria
6 partially stabilized Zirconia (YPSZ) ceramic top coat on the nanostructured, nano-
7 composite bond coat.

1 3. The method of claim 2 where the providing the nanocrystalline, nano-composite
2 coating comprises providing a Ni/Cr/Al/Y system (balance:22:10:1 respectively by wt.%)
3 bond coat disposed on a Ni-based alloy substrate using a high velocity oxy fuel (HVOF)
4 thermal spray process or low pressure plasma spray process (LPPS).

1 4. The method of claim 2 where providing the nanocrystalline, nano-composite
2 coating comprises cryomilling a NiCrAlY powder and thermally spraying the cryomilled
3 NiCrAlY powder onto the substrate in the presence of oxygen.

1 5. The method of claim 4 where cryomilling the NiCrAlY powder comprises
2 cryomilling the powder in a liquid nitrogen environment.

1 6. The method of claim 4 where cryomilling the NiCrAlY powder comprises
2 cryomilling the NiCrAlY powder for at least 8 hours.

1 7. The method of claim 1 where providing the nanocrystalline, nano-composite
2 coating comprises cryomilling a MCrAlY powder in the presence of oxygen, where M
3 stands for either Co, Ni and/or Fe, such that aluminum oxide is formed in the cryomilled
4 powder to serve as a nucleation site for further alumina formation in the top coat and
5 using a high velocity oxy fuel (HVOF) thermal spray process or low pressure plasma
6 (LPPS) spray process to deposit the cryomilled powder onto the substrate.

1 8. The method of claim 7 where providing the nanocrystalline, nano-composite
2 coating comprises thermal spraying in the presence of oxygen to further form aluminum
3 oxide in the sprayed bond coat.

1 9. The method of claim 8 where providing the nanocrystalline, nano-composite
2 coating comprises heat treating the sprayed substrate in the presence of oxygen to
3 induce a thermally grown oxide layer (TGO) thereon.

1 10. The method of claim 9 where heat treating the sprayed substrate in the presence
2 of oxygen to induce a thermally grown oxide layer (TGO) comprising inducing the
3 formation of a continuous α -Al₂O₃ layer on the top of the bond coat.

1 11. The method of claim 1 where providing the nanocrystalline alumina coating
2 comprises cryomilling an alumina powder to achieve nanocrystalline grain sizes and
3 disposing the cryomilled nanostructured alumina composite coating on the bond coat.

1 12. The method of claim 11 where disposing the alumina powder on the bond coat
2 comprises plasma spraying the nanocrystalline alumina powder onto the bond coat in
3 the presence of oxygen.

1 13. A thermal barrier coating comprising:
2 a substrate;
3 a nanocrystalline, nano-composite bond coat on the substrate; and
4 a ceramic top coat on the nanostructured, nano-composite bond coat.

1 14. The thermal barrier coating of claim 13 where the bond coat on the substrate
2 comprises a bond coat composed of nanocrystalline MCrAlY, where M stands for either
3 Co, Ni and/or Fe, using a high velocity oxy fuel (HVOF) thermal spray process or low
4 pressure plasma (LPPS) spray process onto a metallic substrate, and where the
5 ceramic top coat on the nanostructured nano-composite bond coat comprises a Yttria
6 partially stabilized zirconia (YPSZ) ceramic top coat on the nanostructured nano-
7 composite bond coat.

1 15. The thermal barrier coating of claim 14 where the nanocrystalline nano-
2 composite coating comprises a Ni/Cr/Al/Y system (balance:22:10:1 respectively by
3 wt.%) bond coat disposed on a Ni-based alloy substrate using the high velocity oxy fuel
4 (HVOF) thermal spray process or low pressure plasma (LPPS) spray process.

1 16. The thermal barrier coating of claim 14 where the nanocrystalline nano-
2 composite coating comprises a cryomilled NiCrAlY powder which is thermally sprayed
3 onto the substrate in the presence of oxygen.

1 17. The thermal barrier coating of claim 16 where the cryomilled NiCrAlY powder
2 comprises a powder cryomilled in a liquid nitrogen environment.

1 18. The thermal barrier coating of claim 16 where the cryomilled NiCrAlY powder
2 comprises a NiCrAlY powder which has been cryomilled for at least 8 hours.

1 19. The thermal barrier coating of claim 13 where the nanocrystalline nano-
2 composite coating comprises a MCrAlY powder cryomilled in the presence of oxygen,
3 where M stands for either Co, Ni and/or Fe, such that aluminum oxide is formed in the
4 cryomilled powder to serve as a nucleation site for further alumina formation in the top
5 coat and which cryomilled powder is disposed onto the substrate using a high velocity
6 oxy fuel (HVOF) thermal spray process.

1 20. The thermal barrier coating of claim 19 where the nanocrystalline nano-
2 composite coating comprises a thermal sprayed bond coating which is sprayed onto the
3 substrate in the presence of oxygen to further form aluminum oxide in the sprayed bond
4 coat.

1 21. The thermal barrier coating of claim 20 where the bond coat and nanocrystalline
2 nano-composite coating comprises a sprayed bond coat which has further been heat
3 treated in the presence of oxygen to induce a thermally grown oxide layer (TGO)
4 thereon.

1 22. The thermal barrier coating of claim 21 where heat treated nano-composite bond
2 composite has a continuous α -Al₂O₃ layer on the bond coat.

1 23. The thermal barrier coating of claim 13 where the nanocrystalline nano-
2 composite coating comprises a cryomilled alumina powder which has been sufficiently
3 cryomilled to achieve nanocrystalline grain sizes.

1 24. The thermal barrier coating of claim 23 where the nanocrystalline nano-
2 composite coating is further plasma sprayed onto the bond coat in the presence of
3 oxygen.

1 25. A method for improving a MCrAlY thermal barrier coating made from MCrAlY
2 powder, where M is a metal or metal alloy, comprising:
3 providing a MCrAlY bond coat on a substrate; and
4 providing a nanocrystalline nano-composite coating on the MCrAlY bond coat
5 with a nanostructured nano-composite-bond coat by refining the microstructure of the
6 MCrAlY powder to nanocrystalline grain size.

1 26. The method of claim 25 further comprising providing a ceramic top coat on the
2 nanostructured nano-composite-bond coat.

3 27. The method of claim 25 where refining the microstructure of the MCrAlY powder
4 to nanocrystalline grain size comprises cryomilling the MCrAlY powder during which the
5 microstructure of the MCrAlY powder is refined to nanocrystalline grain size through the
6 *in-situ* formation of oxides, nitrides and/or oxynitrides.

1 28. The method of claim 25 where refining the microstructure of the MCrAlY powder
2 to nanocrystalline grain size comprises cryomilling the MCrAlY powder and refining the
3 microstructure of the MCrAlY powder to nanocrystalline grain size during cryomilling
4 through the introduction of Al₂O₃ particles during cryomilling.

1 29. The method of claim 28 where refining the microstructure of the MCrAlY powder
2 to nanocrystalline grain size during cryomilling comprises introducing nano alumina
3 particles during cryomilling.

1 30. The method of claim 28 where refining the microstructure of the MCrAlY powder
2 to nanocrystalline grain size after cryomilling comprises introducing nano alumina
3 whiskers during cryomilling.

1 31. A MCrAlY thermal barrier coating made from MCrAlY powder, where M is a metal
2 or metal alloy, comprising:
3 a MCrAlY bond coat on a substrate; and
4 a nanostructured nano-composite bond coat with nanocrystalline size MCrAlY
5 grains.

1 32. The thermal barrier coating of claim 31 further comprising a ceramic top coat on
2 the nanostructured nano-composite-bond coat.

3 33. The thermal barrier coating of claim 31 where the nanocrystalline size MCrAlY
4 grains are formed by cryomilling the MCrAlY powder during which the microstructure of
5 the MCrAlY powder is refined to nanocrystalline grain size through the *in-situ* formation
6 of oxides, nitrides and/or oxynitrides.

1 34. The thermal barrier coating of claim 31 where the powder nanocrystalline size
2 MCrAlY grains are formed by cryomilling the MCrAlY powder and refining the
3 microstructure of the MCrAlY powder to nanocrystalline grain size after cryomilling
4 through the introduction of Al₂O₃ particles during cryomilling.

1 35. The thermal barrier coating of claim 34 where the nanocrystalline size MCrAlY
2 grains formed after cryomilling arise from nano alumina particles introduced during
3 cryomilling.

4 36. The thermal barrier coating of claim 34 where the nanocrystalline size MCrAlY
5 grains formed after cryomilling arise from nano alumina whiskers introduced during
6 cryomilling.